

The Developing
Moderate Resolution Imaging Spectroradiometer (MODIS)
Snow Cover Algorithm

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ABSTRACT

Elements of the snow cover algorithm to be implemented with the Earth Observing System (EOS) MODerate resolution Imaging Spectroradiometer (MODIS), scheduled for launch in 1998, are developed and tested. The MODIS snow cover algorithm will generate global and regional snow cover data products weekly. The algorithm utilizes unique spectral and spatial characteristics of the MODIS to identify snow by reflectance characteristics. The algorithm implements a series of criteria tests and a Normalized Snow Difference Index (NSDI) to identify snow and discriminate snow from many types of clouds. Landsat Thematic Mapper (TM) data, simulated MODIS data, and Advanced Very High Resolution Radiometer (AVHRR) data are used to prototype the algorithm. The snow cover algorithm has been tested on a variety of Landsat TM scenes with consistent snow identification results.

MODIS INSTRUMENT

The MODerate resolution Imaging Spectroradiometer (MODIS) is an Earth Observing System (EOS) instrument designed to measure biological and physical process on a global basis every one to two days. Slated for both the EOS-AM and PM satellite series, MODIS will provide long-term observations of the earth for study of global dynamics and processes occurring on the surface of the Earth and in the lower atmosphere. MODIS employs a conventional imaging radiometer concept, consisting of a cross-track scan mirror and collecting optics, and a set of linear detector arrays with spectral interference filters located on four focal planes. The optical arrangement will provide imagery in 36 discrete bands between 0.4 and 15.0 μ m selected for diagnostic significance in Earth sciences. Spatial resolution will be 250 m (2 bands), 500 m (5 bands), or 1 km (29 bands) at nadir. Each MODIS in the EOS series will provide daylight reflection and day/night emission spectral imaging of any point on earth at least every two days, with a continuous duty cycle (Salomonson and Toll, 1991; NASA, 1993).

SNOW REFLECTANCE CHARACTERISTICS

Snow typically has high reflectance in the visible region of the spectrum. Nearly 80% of incident solar radiation may be reflected from fresh snow (Choudhury and Chang, 1981; Hall, et al., 1990a). Snow

reflectance decreases as snow ages or becomes contaminated by deposition of aerosols, soot, pollen, etc. (Warren, 1982; Dozier, 1984), yet remains much brighter than most other surfaces. It is the high reflectance characteristics of snow in the visible portion of the spectrum that make it distinguishable from many other surface features. In the near infrared, snow and clouds have different reflectance characteristics; clouds have high reflectance, snow has low reflectance. It is this difference in reflectance between snow and clouds at 1.6 μ m that makes it possible to distinguish between the two (Allen et al., 1990; Dozier, 1989). These reflectance characteristics of snow form the basis for the prototype MODIS snow algorithm.

MODIS SNOW COVER ALGORITHM

The purpose of the MODIS snow cover algorithm is to generate a snow cover product useful in global change research, ecological research and as input to hydrological models. The snow cover product is to be generated in concert with a group of MODIS global survey products. This group of products will be generated using automated techniques. Segments and capabilities of the MODIS snow cover algorithm are developed with other sensors, i.e., Landsat Thematic Mapper (TM), AVHRR, and MODIS Airborne Simulator (MAS). Data from these sensors is used to develop and test segments of the algorithm for detecting snow cover, snow and cloud discrimination, and cloud screening before the launch of MODIS. Because no orbiting satellites have the capabilities of MODIS, components of the MODIS algorithm must be developed and tested with these other sensors. The components will merge into an MODIS algorithm that uses information from the visible, infrared and emitted wavelengths to identify snow and discriminate snow from clouds.

The snow cover algorithm is a structured series of tests designed to identify snow by its reflectance characteristics, discriminate clouds from snow, and screen out cirrus clouds based on the differing characteristics of water vapor clouds and cirrus clouds (Riggs, et al., 1992). Bands in visible, infrared and emitted wavelengths will be used in the MODIS snow cover algorithm. The tests are essentially threshold tests for reflectance or emittance characteristics of snow. A normalized snow difference index (NSDI) has been defined to help in identifying snow.

Normalize Snow Difference Index

The normalized snow difference index (NSDI) is based on the fact that snow has a high reflectivity in the

visible wavelengths and is a strong absorber of near infrared radiation. This relationship gives an index that is used to identify snow from other surface features. The NSDI identifies the characteristic change in snow reflectance between the visible and near infrared spectral regions. Snow should ideally have NSDI values near 1.0. For TM data the NSDI is calculated as:

$$\text{NSDI} = (\text{TM band 2} - \text{TM band 5}) / (\text{TM band 2} + \text{TM band 5})$$

Snow has been found to have NSDI values typically 0.5. The NSDI alone could be used to identify snow cover but using it in conjunction with other tests has increased accuracy of snow identification. Snow, sunlit and shaded, can be separated from clouds and nonsnow covered surfaces when the NSDI is used in conjunction with a threshold test for TM band 4 reflectance (Figure 1).

Algorithm Structure

The decision logic of the algorithm for TM data (Figure 2) begins with a test for high visible reflectance, to separate snow and other highly reflective features from those of low reflectivity. At the 30 m spatial resolution of the TM it is possible to identify snow shaded by clouds and terrain features. The NSDI value is then tested for on both high and low reflectance pixels. If the NSDI value is 0.6 or greater then the pixel is considered to be either sunlit or shaded snow. A further check of reflectance in TM band 4 is done to separate snow from other possible features. Then a check is performed using thermal-infrared data, to separate snow from other features. It is assumed that snow is always at a temperature of 273° K or less. One further check is done to separate water from shaded snow. It has been observed that water bodies such as lakes and rivers are sometimes confused with shaded snow, so a test to screen out water was added to remove this confusion. This test identifies pixels that have 10% reflectance in the visible and near infrared as water.

Values for the threshold reflectance tests and NSDI are based on published snow reflectances and from sampling of snow, clouds, and other surface features from several different Landsat TM images. A reference set of threshold values has been adopted based on these samples. The adopted values were determined after recursive testing and analysis at different values and combinations of values on a variety of scenes. These chosen reference thresholds are applied to any TM scene.

Because decisions are made on reflectance, TM data is converted to reflectance values. Conversion to reflectance is done separately from the algorithm using procedures, equations and constants given by Hall et

al. (1990b), and Markham and Barker (1986). Each scene is unique because of the dependence on solar zenith angle. Once the conversion to reflectance has been made, the algorithm may be implemented with the reflectance values.

RESULTS

The snow cover algorithm has been developed and tested with Landsat TM scenes of mountainous regions in North America, and other areas. Results from study of a scene of Glacier National Park, Montana, are the focus of this discussion. This scene was imaged on 14 March 1991 (Figure 3a). There is snow in the mountains and cloud cover over the mountains in the Park and to the west; much of the land to the east of the mountains is not snow covered. Visual interpretation of the location and extent of snow cover in a false color composite was in harmony with snow cover location and extent identified by the algorithm (Figure 3b). Without specific knowledge of conditions on the ground at the time it is not possible to make a rigorous quantitative analysis. Snow, both sunlit and shaded, was identified for 31% of the image. No clouds were misidentified as snow. Errors of omission are the most likely source of error in the results. The reason for a bias toward errors of omission is that reflectance threshold values have been set at a high level to minimize errors of commission. The trade off with high threshold acceptance values is to omit pixels that may be snow.

Sensitivity of Threshold Method

The effect of changing a threshold value is to change the amount of snow identified by the algorithm in a scene. It has been our experience that incremental stepping up or down of the threshold values results in 10% to 20% change in the amount of snow cover per step. Amount of change in snow cover is dependent upon the amount of snow in a particular scene. Spatially, changing thresholds results in an expansion or contraction of snow extent about the perimeters of snow areas identified with the previous threshold settings. This has been observed over a range of thresholds above and below what was considered the best threshold value result. An example of the change in amount of snow cover that occurs for stepping the NSDI is shown in Figure 4. This type of analysis suggests the sensitivity of using the thresholding technique. A general analysis that can be made is that near either the highest or lowest threshold values, radical jumps in amount of snow cover mapped may be observed, but for a range of values between, changes in snow cover between

threshold values are relatively small. There are not exact threshold settings, but there are ranges of acceptable thresholds that give relatively good qualitative results. These universal thresholds pose a problem because they are not scene-specific. It is planned to link threshold settings to scene reflectance based on viewing geometry and empirically-derived scene radiance.

Other TM Scenes

The snow cover algorithm has been applied to several other TM scenes, some having snow cover and others having no snow cover. This has been done recursively in deciding what threshold levels to adopt, and to find situations where the algorithm would fail to yield satisfactory results. It was found that cirrus clouds are very difficult to screen and distinguish from snow, unless they are specifically sampled from an image to determine the threshold that can be used to screen them out.

Simulated MODIS Data

Simulated MODIS data were generated for a subset of a TM image of the Chugach Mountains, Alaska using the technique described by Barker et al. (1992). The area was selected for its view of mountain snow, glaciers, water, vegetated land, and cloud cover. Simulation of MODIS data was done by spatial filtering 30 m TM data in the frequency domain, and resampling to produce 250 m, 500 m, or 1000 m simulated MODIS imagery. The simulated data were scaled to 12 bit integer, the precision expected for MODIS. TM radiance values were the starting data for the simulation procedure. The MODIS prototype TM snow algorithm was applied to the original TM image and the simulated MODIS image. To apply the algorithm to the simulated MODIS data, the threshold values for the reflectance tests were adjusted to equivalent simulated MODIS (12 bit) data values.

The spatial degradation from 30 m TM to coarser resolution simulated MODIS data resulted in fewer pixels, and a blurred appearance in the simulated image. Fewer snow covered pixels were identified in the simulated MODIS image due to the combination of spatial degradation and lack of spatially extensive areas of snow in the image. When the snow algorithm was applied to the original TM image, approximately 21% of the image was identified as snow covered. When the TM snow algorithm was directly applied, with TM reference threshold values to the simulated MODIS image only about 1% of the MODIS image was identified as snow. This difference may be attributable to the degraded resolution, conversion to dynamic range of simulated MODIS values, and different spatial resolutions of the MODIS bands. If the threshold

value for only the NSDI test was changed in the algorithm, a snow cover extent that was visually similar to that identified in the original TM image could be arrived at. At the best visual harmony between the images, approximately 8% snow cover was found for the simulated MODIS data. Analysis of these results suggest that modifications of the snow cover algorithm to adjust for the different dynamic range of MODIS and the differences in spatial resolutions (250 m, 500 m, and 1000 m) between MODIS bands expected to be utilized will be necessary.

AVHRR Data

A snow algorithm for AVHRR data is also being developed. The objective of using AVHRR data is to prototype a weekly snow cover logic to capture the dynamics of snow cover on a time scale similar to changes in vegetation indices or greenness values. A prototype algorithm for AVHRR data has been developed for AVHRR imagery covering Alaska. The prototype algorithm is based on the snow identification techniques used by NOHRSC. The snow algorithm for AVHRR data is modeled on that used by NOHRSC and described by other researchers (Allen, et.al., 1990; Carroll, 1990; Holyroyd, et.al., 1989; Szeliga, et.al., 1990). Snow is identified by high reflectance in the visible (Channel 1, 0.58 - 0.68 m) and snow/cloud discrimination is done with Channel 3 (3.55-3.93 m) - Channel 4 (10.30-11.30 m) difference. The AVHRR snow algorithm is prototyping a temporal snow cover product for MODIS. An objective of using AVHRR data is to establish a time series of data to use in prototyping a temporal snow cover algorithm and product for MODIS. This will probably be a weekly snow cover data set that contains information on the extent and dynamics of snow cover.

FUTURE DIRECTION

The snow cover algorithm will continue to be modified in response to testing and analysis findings over the next several years. Because the project requirement is that the algorithm is executed automatically without an interpreter's intervention, the methods used must be automatable. It is our intention to continue pursuing the use of automatable tests, such as those described here, for snow reflectance characteristics. Some initial comparisons with other methods of snow identification suggest that the results of this method generally agree with others. The importance of these initial comparisons of methods is that they generally agree; wildly divergent results have not been found. It is anticipated that the decision rules for these tests will be based on

snow reflectance characteristics and that selection of decision or threshold values will be empirically linked to viewing parameters at the time of acquisitions. Results using TM data and simulated MODIS data reinforce the idea that threshold values should be empirically linked to scene geometry and radiance. The infrared bands of MODIS should allow discrimination of many types of clouds from snow, and the 1.38 μ m MODIS band should allow for reliable screening of cirrus clouds. According to Kaufman (1993) cirrus clouds can be detected at 1.38 μ m.

Over the next four years, before launch, the algorithm will evolve into an at-launch form and be integrated with the group of MODIS Land Group algorithms for product generation in the EOS Data Information System (EOSDIS).

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Figure 1. Relationship of NSDI to TM band 4 reflectances for four features sampled from a Landsat TM image of the Brooks Range, Alaska.

Figure 2. Decision structure of the snow cover algorithm for Landsat TM data.

Figure 3. Images of Glacier National Park, 14 March 1991; (a) band combination image, (b) snow cover result from snow cover algorithm (white is snow, black is not snow).

Figure 4. Change in number of identified snow pixels for a change in the NSDI acceptance threshold value.

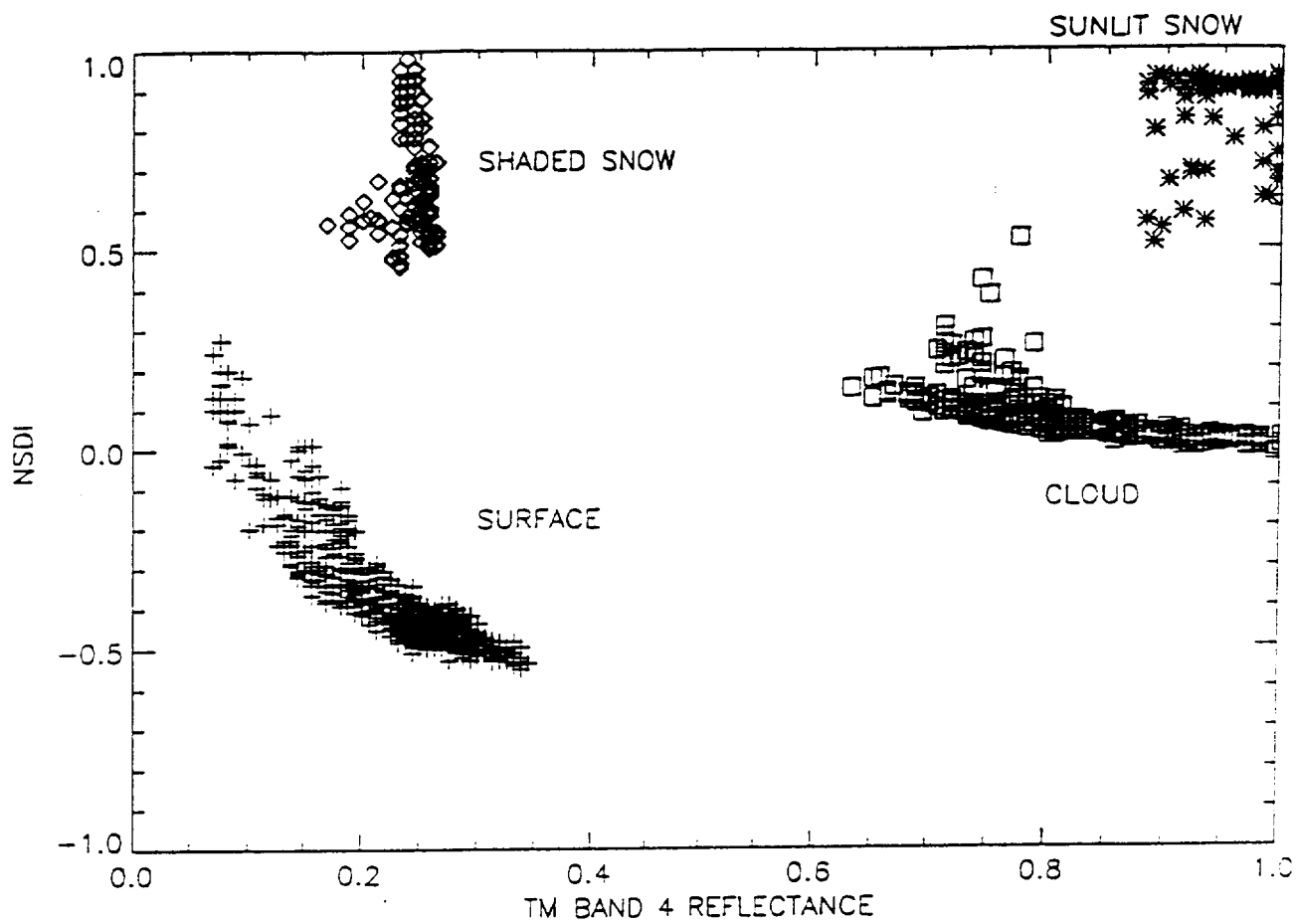


FIGURE 1

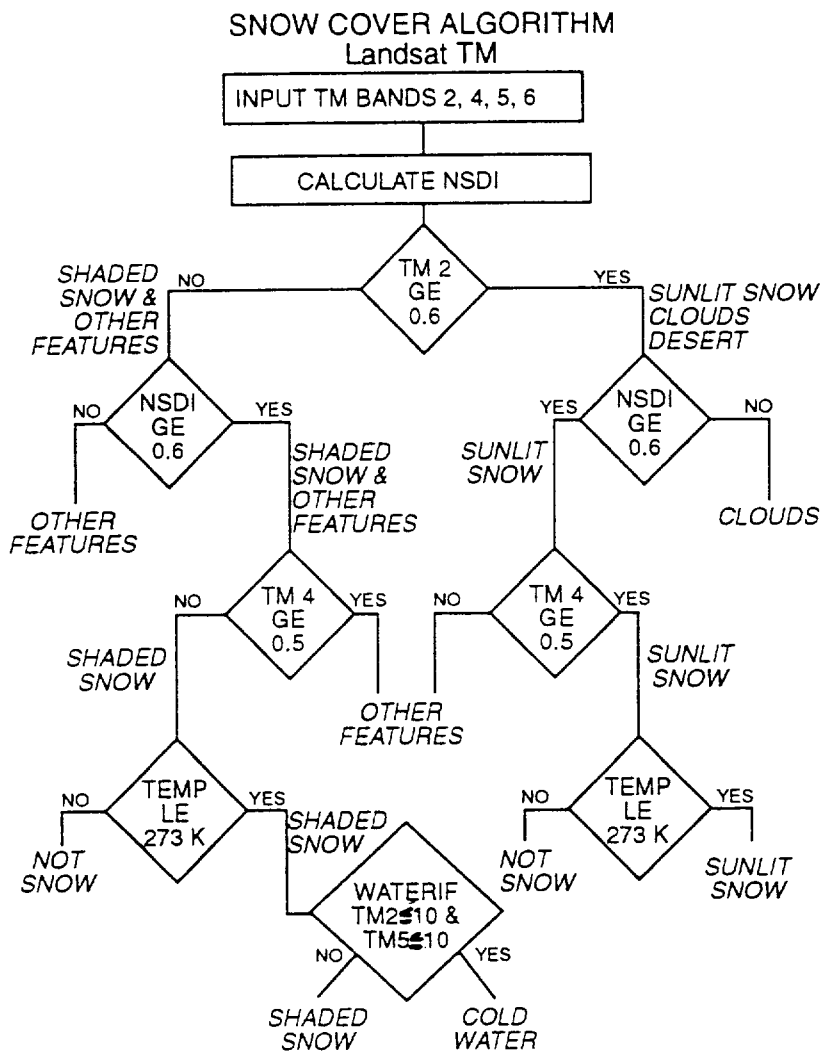
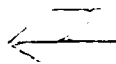


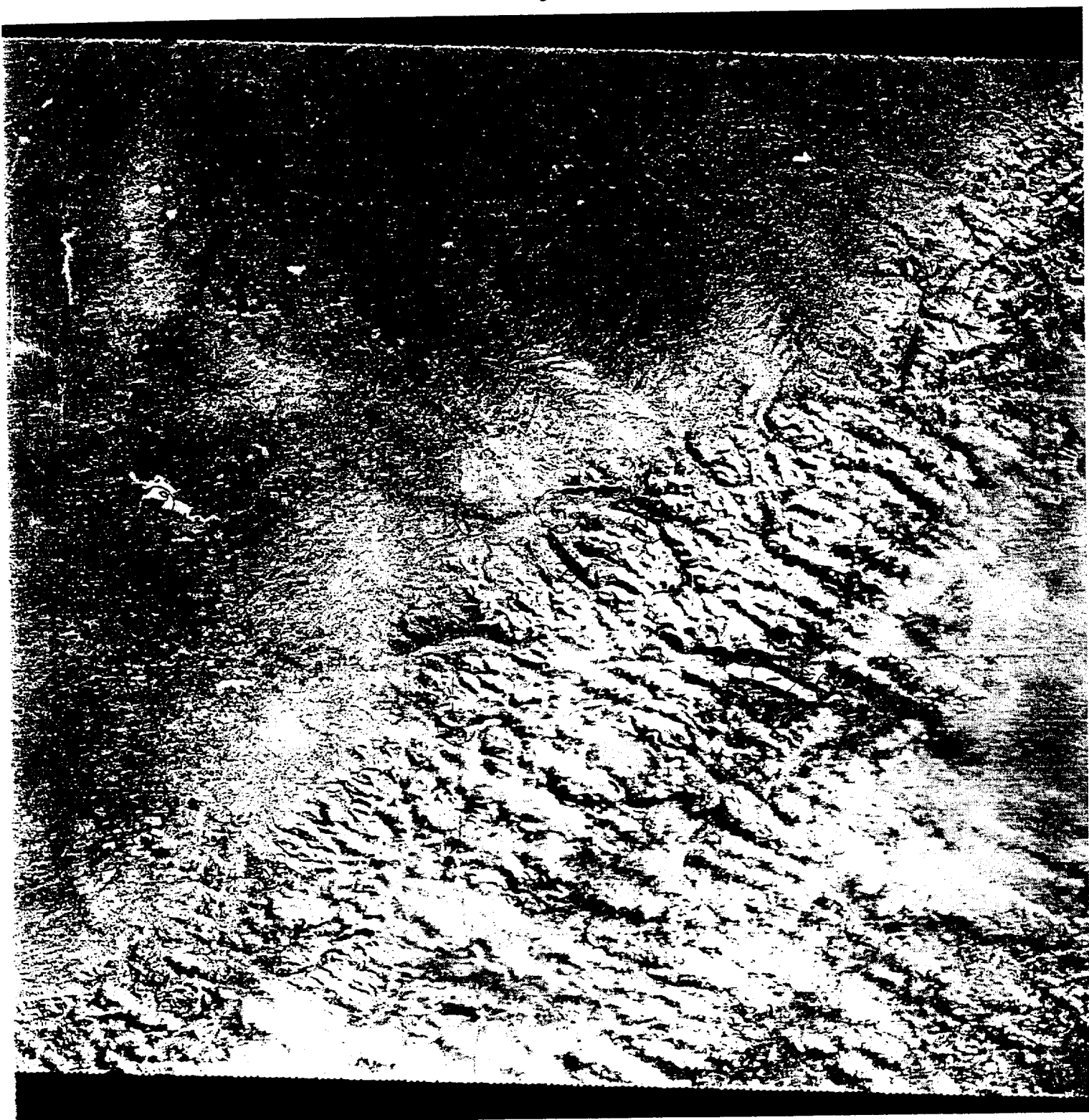
FIGURE 2



- 1. L. Ke. in P. 116
- 2. 24 May 1964
- 3. Lower St.
- 4. P. 116
- 5. 24 May 1964
- 6. 24 May 1964
- 7. P. 116
- 8. 24 May 1964

6/6/1964 to 11/11/64
Lower St.
P. 116

6971, 5965
p. 116



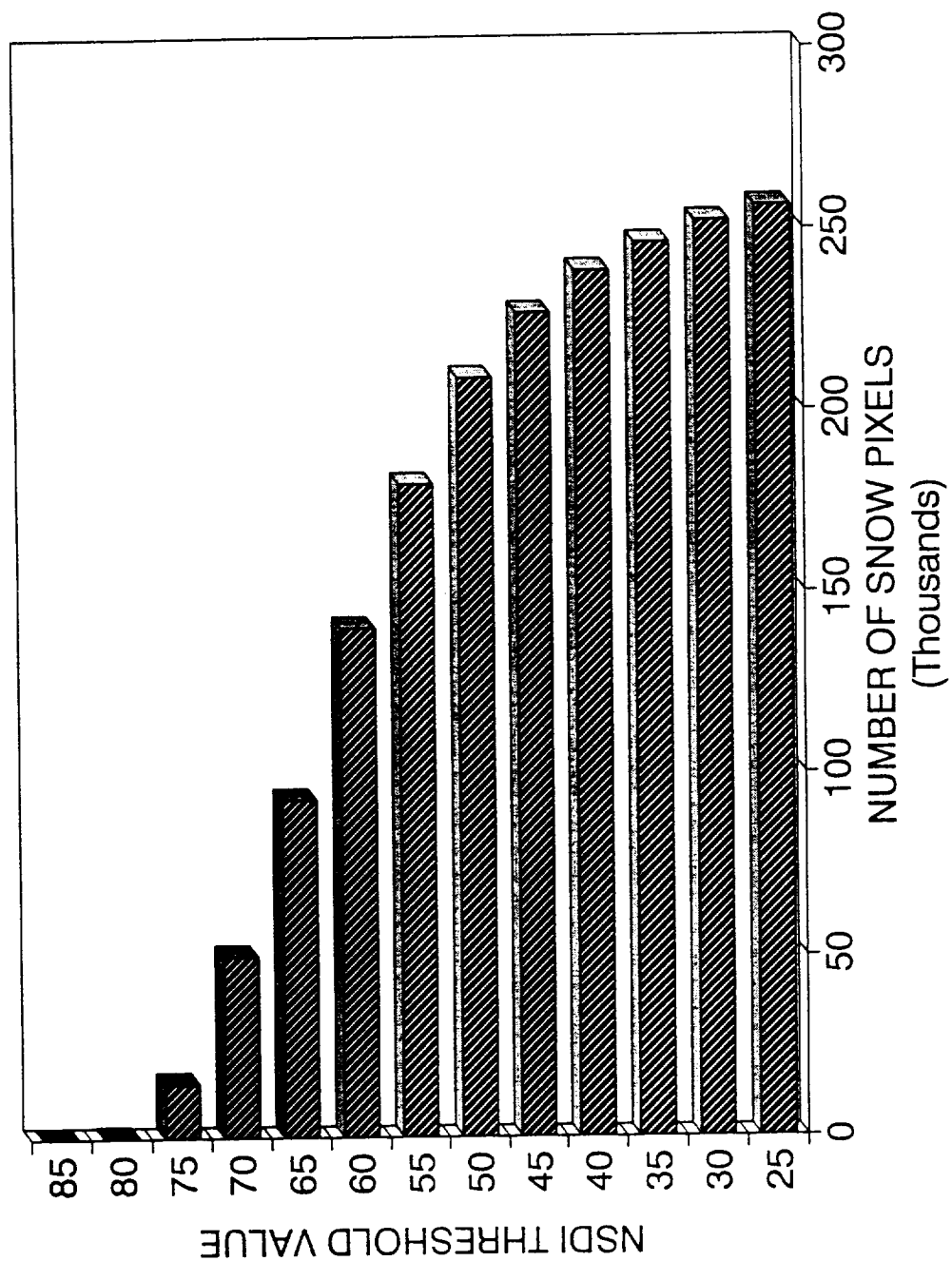


FIGURE 4